DEVOLATILIZATION STUDIES OF OIL PALM PLANTATION RESIDUES VIA TORREFACTION PROCESS

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ABSTRACT

Biomass represents a type of renewable energy source that will play a substantial role in the future global energy balance in terms of energy security and carbon-neutral fuel. However, raw lignocellulosic biomass presents several undesired properties such as low energy density, hygroscopic nature, and low bulk density that do not permit its direct exploitation. Torrefaction, an emerging thermal pretreatment process, is acknowledged to improve the fuel properties of raw biomass towards an efficient renewable energy supply. This paper investigates the fuel characteristics of OPF and OPT at temperatures: 200˚C, 250˚C, and 300˚C at a constant heating rate of 10˚C/min and 30 min residence time. The torrefied products were characterized in terms of their moisture content, calorific value, mass an energy yield. Prediction of calorific value based on the colour of torrefied biomass was also presented here. Bomb calorimeter was used to measure the calorific value in order to calculate mass and energy yield for analysis. In addition, Fourier Transform Infrared (FTIR) Spectroscopy, Thermogravimetric Analysis (TGA), and Derivative Thermogravimetric (DTG) analysis were performed to investigate the changes of lignocellulosic physicochemical properties of the studied materials. As a result, both OPF and OPT with calorific value of 16.41 MJ/kg and 17.41 MJ/kg were improved to 22.46 MJ/kg and 25.48 MJ/kg respectively after torrefaction at 300˚C. The mass yield for both samples decrease at elevated torrefaction temperature while retaining their energy yield between 90-100%. The degradation behaviours of lignocellulosic components: hemicellulose, cellulose, and lignin were discussed through FTIR, TGA, and DTG analysis. Meanwhile, the improved hydrophobic characteristic was also justified. This work concludes that OPF and OPT made a good biomass for torrefaction purpose which can be upgraded to universal energy commodity.

ABSTRAK

Biojisim mewakili sejenis sumber tenaga yang boleh diperbaharui dan ia memainkan peranan penting dalam imbangan tenaga global masa hadapan dari segi keselamatan tenaga dan sebagai bahan api karbon-neutral. Walau bagaimanapun, biojisim lignoselulosik mentah mempunyai beberapa karakteristik yang tidak diingini seperti kepadatan tenaga yang rendah, sifat hidroskopis, dan ketumpatan pukal yang rendah serta tidak membenarkan eksploitasi langsung. Torrefaksi adalah satu proses prarawatan termal untuk meningkatkan sifat-sifat bahan api biojisim mentah ke arah bekalan tenaga yang boleh diperbaharui dan cekap. Kertas ini mengkaji ciri-ciri bahan api OPF dan OPT pada suhu torrefaction: 200˚C, 250˚C, 300˚C pada kadar pemanasan 10˚C/min dengan masa tinggal 30 min. Produk torrefaksi telah dicirikan dari segi kandungan kelembapan, nilai kalori, jisim dan hasil tenaga. Ramalan nilai kalori berdasarkan warna biojisim torrefaksi telah juga dibentangkan. Bom kalorimeter digunakan untuk mengukur nilai kalori bagi mengira jisim dan tenaga hasil untuk analisis. Di samping itu, Fourier Transform Infrared (FTIR) Spektroskopi, Analisis Termogravimetri (TGA), dan derivatif Termogravimetri (DTG) analisis telah dijalankan untuk menyiasat perubahan sifat fizikokimia lignoselulosa daripada bahan yang dikaji. Akibatnya, kedua-dua OPF dan OPT dengan nilai kalori 16.41 MJ/kg dan 17.41 MJ/kg telah meningkat kepada 22.46 MJ/kg dan 25.48 MJ/kg masing-masing selepas torrefaksi pada suhu 300˚C. Hasil massa untuk kedua-dua sampel dikurangkan apabila suhu torrefaksi meningkat, pada masa yang sama hasil tenaga mereka dikekalkan di antara 90-100%. Tingkah laku degradasi komponen lignoselulosa: hemiselulosa, selulosa, lignin dan telah dibincangkan melalui analisis FTIR, TGA, dan DTG. Sementara itu, ciri hidrofobik yang bertambah baik juga telah diwajarkan. Kerja ini menyimpulkan bahawa OPF dan OPT merupakan biojisim baik untuk tujuan torrefaction yang boleh dinaik taraf kepada komoditi tenaga universal.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

CV	*Calorific value*
e_1	correction in calories for heat of formation of nitric acid
e_2	correction in calories for heat of formation of sulfuric acid
e_3	correction in calories for heat of combustion of fuse wire
m	mass of sample
t	temperature rise
W	constant of eq.(3.2)

LIST OF ABBREVIATIONS

CPO	Crude palm oil
CV	Calorific value
DTG	Derivative Thermogravimetric
EFB	Empty fruit bunch
FFB	Fresh fruit bunch
FTIR	Fourier Transform Infrared
GHG	Greenhouse gas
HHV	Higher heating value
MC	Moisture content
OPF	Oil palm frond
OPT	Oil palm trunk
PKS	Palm kernel shell
POME	Palm oil mil effluent
TG	Thermogravimetric
TGA	Thermogravimetric Analysis

1 INTRODUCTION

1.1 Motivation and statement of problem

World primary energy demand, reported as 524 quadrillion British thermal units (Btu) in 2010, is expected to increase by 56% in 2040 (EIA, 2013). Energy security and environmental sustainability are major emerging issues which can only be addressed through diversification in energy resources and clean fuels. The extent of greenhouse gas (GHG) emission by fossil fuel is so significant due to the urgent need to reduce the carbon footprint of the world via the usage of alternative energy sources that are benign to the environment (Ossai *et al*., 2013). The growing concerns about future depletion of fossil fuels and accumulation of their emissions in the environment have attracted world's attention to exploit and utilize renewable energy sources and low carbon fuels. It is realized that a continuous reliance on fossil fuels will have catastrophic results because excessive carbon dioxide emission has dramatic global warming effects (Awan & Khan, 2014). Volatility of oil prices and its high demand have also encouraged global community to reduce the dependence on oil and replace it with clean and renewable energy resources (Fauzianto, 2014). On the other hand, the implementation of national targets to increase the amount of renewable energy and reduce GHG emissions is accelerating the utilization of resources such as solar, wave, wind, tidal, and biomass. These resources have their own unique advantages and disadvantages.

Biomass is a unique renewable resource. It appears to be a promising alternative energy resource to replace fossil fuels in the future. As a sustainable carbon carrier, biomass, unlike fossil fuels, is planted and collected annually which provides a continuous energy supply. Biomass is a carbon-neutral fuel as its carbon is recycled from the atmosphere. In addition, biomass can exist in the form of solid (briquette, pellet, char), liquid (biodiesel, ethanol), or gaseous (biogas) fuel which makes it ideal for 100% renewable energy systems as it can be fully utilized in heat and electricity generation, and even the transport sectors (Mathiesen *et al*., 2012). Therefore, biomass plays a substantial role in the future energy scenarios.

Biomass however, presents several undesired properties that do not permit its direct exploitation. Raw biomass is classified as low grade fuel that associates with several

shortcomings like structural heterogeneity, non-uniform physical properties, low energy density, hygroscopic nature, and low bulk density. These drawbacks create difficulties in several aspects such as transportation, storage complications, lower thermal-conversion efficacy and utilization limitations (Xue *et al*., 2014). In order to overcome these problems, the properties of raw biomass need to be modified. A viable option is to carry out a thermochemical pre-treatment process, specifically the torrefaction process.

Torrefaction is a mild pyrolysis process which undergoes thermal decomposition of biomass in the inert atmosphere with the absence of oxygen. It is characterized by low particle heating rate (<50˚C/min) with an operating temperature typically ranging from 200˚C to 300˚C and a residence time not more than one hour (Chen & Kuo, 2010). The biomass partly decomposes, giving off various types of volatiles during the process. The solid product, namely torrefied biomass will result in loss of mass and chemical energy to the gas phase, leaving a biomass with improved properties which make it attractive for further utilizations such as combustion and gasification in general (Baskar *et al*., 2012).

Oil palm (*Elaeis guineensis*) is an agro-industrial commodity and the principal source of palm oil. Malaysia, as the second largest oil palm-producing country that comes after Indonesia, accounts for 39% of world's palm oil production and 44% of world's exports (MPOC, 2009). There are abundant raw materials available from the oil palm trees which constitute a 10% of oil and the rests are classified as biomass residues (Abdullah & Sulaiman, 2013). These residues can be sorted into two types: oil palm plantation residues consisting of oil palm fronds (OPF) and oil palm trunks (OPT), as well as oil palm mill residues consisting of empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fibre, and palm oil mill effluent (POME). In order to seek benefits from these biomass residues, several researches have examined the potential of energy generation from these agricultural wastes (Lai & Idris, 2013; Lu *et al.*, 2012; Peng *et al*., 2012; Sulaiman *et al*., 2009; Van der Stelt *et al*., 2011; Wannapeera *et al*., 2011).

Torrefaction process on oil palm biomass has gained interest among the researchers towards its potential products for energy generation. However, major studies only emphasized on the wastes or by-products obtained from palm oil mills, i.e., EFB, PKS, mesocarp fiber, and POME whereas the wastes obtained from plantation sites such as OPF and OPT are currently underutilized due to the limited knowledge available on

their respective. Hence, this research was experimentally conducted to understand the physical and chemical processes in torrefaction of OPF and OPT as well as to fully utilize its usability and economic value towards a better development of Malaysia in terms of renewable energy source.

1.2 Objectives

The following is the objective of this research:

- To study the torrefaction effect on physicochemical properties of oil palm fronds (OPF) and oil palm trunks (OPT) at different temperature levels

1.3 Scope of this research

The following are the scopes of this research:

i) Experimental analysis of torrefaction behaviour of OPF and OPT at different temperature ranging within 200–300˚C
ii) Prediction of calorific value at various torrefaction temperature for OPF and OPT based on their colours using RGB colour model
iii) Characterization of moisture content and calorific value for mass and energy yield analysis
iv) Characterization analysis on lignocellulosic structure of OPF and OPT via Fourier Transform Infrared (FTIR) Spectrometry and Thermogravimetric Analysis (TGA) for devolatilization studies

1.4 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 mainly discusses on the information gathered and the reviews related to the topic concerned. It starts with the biomass review in which general information of biomass and its sources are provided. Then, the properties of lignocellulosic biomass and its major constituents (cellulose, hemicellulose, and lignin) are briefly discussed. This is followed by a discussion on the palm oil and oil palm biomass in Malaysia together with oil palm fronds (OPF) and oil palm trunks (OPT) as its subchapters. Several biomass conversion methods and torrefaction process, which is the main study in this research, are also elaborated in detail. Extensive reviews on the operating

parameters affecting the thermal treatment process are also presented. Last but not least, the effect of biomass colour on calorific value is discussed.

Chapter 3 provides a discussion on samples preparation, methods, and measurements applied in this research. The preparation of samples from converting raw materials into desired fibrous samples until storage handling prior to experimental purpose is discussed. This is then followed by a brief discussion on the torrefaction method used in this study. Besides, a detailed discussion on calorific value prediction based on colour of biomass is presented. In addition, this chapter also provides the methods used to characterize moisture content and calorific value, as well as performing FTIR spectrometry and Thermogravimetric Analysis (TGA). Lastly, measurements for mass and energy yield are formulated as well in this chapter.

Chapter 4 is devoted to the results which cover the moisture content, predicted and experimental calorific value, mass and energy yield, FTIR analysis, TG-DTG analysis for both raw and torrefied OPF and OPT. The results are further discussed based on previous studies and researches.

Chapter 5 concluded the results for this work and necessary recommendations are added in order to enhance the future researches related to this work.

2 LITERATURE REVIEW

2.1 Overview

This paper presents the reviews related to the experimental studies of torrefaction process, a thermal pretreatment method to convert raw biomass into added value solid product with enhanced fuel properties. The chapter starts with an informative description of biomass, followed by its lignocellulosic properties that explain the reason of choosing OPF and OPT as raw materials for torrefaction studies in this research. In addition, extensive reviews are made to compare various biomass conversion methods and studies on previous research operating parameters give a better understanding on the effect of temperature towards torrefaction behaviour which in turn led to the objective in this study.

2.2 Biomass

The term biomass (Greek *bio* meaning *life* + *maza* meaning *mass*) refers to any biological matter derived from the living organism such as plants and animals. It is different from the organic materials which have been transformed by geological processes for millions of years into primitive substances such as coal or petroleum (Demirbas, 2009). Biomass is recognized as a renewable energy since solar energy can be stored and converted into chemical energy via photosynthesis during the growth of plants and trees, and then released through direct or indirect combustion for heat and electricity generation. Presence of sunlight triggers the photosynthesis of green plants where water molecules are broken down to obtain electrons and protons that contribute in converting carbon dioxide into glucose and oxygen as the final products (Basu, 2010). During the process, the chlorophyll promotes the absorption of carbon dioxide from the atmosphere which facilitates the growth of the plant. Figure 2-1 displays a summary on the growth of photosynthetic biomass.

Each year, a vast amount of biomass grows through photosynthesis by capturing and concentrating the carbon dioxide directly from the atmosphere. Burning of biomass subsequently releases the carbon dioxide back again to the atmosphere. Thus, any burning of biomass does not add to the Earth's carbon dioxide inventory. For this reason, biomass is said to be "carbon-neutral" (Basu, 2010). Furthermore, due to negligible

amount of sulphur and nitrogen contents, biomass upon burning does not contribute to acid rain gases, thus it is recognized as a clean fuel (Demirbas, 2008).

Biomass encompasses a wide array of materials such as forestry, agricultural, and agro-industrial residues, as well as municipal and industrial wastes. Table 2-1 presents a general classification of biomass types according to their supply sector. Forestry and agriculture sector are two main resources representing the primary sources of biomass whereas industry and waste residues are secondary sources of biomass derived from primary sources.

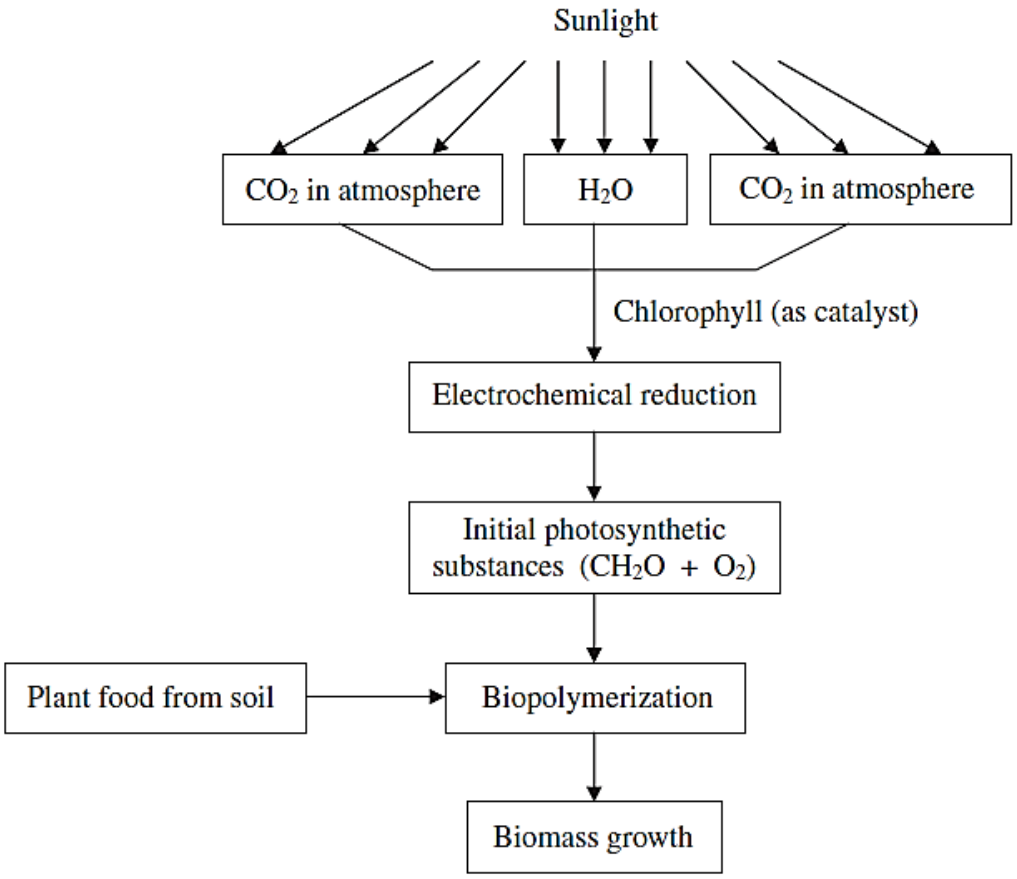


Figure 2-1: Steps of photosynthetic biomass growth (Demirbas, 2009)

Table 2-1: General classification of biomass resources (EUBIA, 2012)

Supply sector	Type	Example
Forestry	Dedicated forestry	Short rotation plantations (e.g. willow, *populus*, *eucalyptus*)
	Forestry by-products	Wood blocks, wood chips from thinning
Agriculture	Dry lignocellulosic energy crops	Herbaceous crops (e.g. *miscanthus*, reed canarygrass, giant reed)
	Oil, sugar and starch from energy crops	Oil seeds for methylesters (e.g. rape seed, sunflower), sugar crops for ethanol (e.g. sugar cane, sweet sorghum), starch crops for ethanol (e.g. maize, wheat)
	Agricultural residues	Straw, prunings from vineyards and fruit trees
	Livestock waste	Wet and dry manure
Industry	Industrial residues	Industrial waste wood, sawdust from sawmills, fibrous vegetable waste from paper industries
Waste	Dry lignocellulosic waste	Residues from parks and gardens (e.g. prunings, grass)
	Contaminated waste	Demolition wood, organic fraction of municipal solid waste, biodegradable landfilled waste, landfill gas, sewage sludge

2.3 Properties of Lignocellulosic Biomass

Biomass can be classified into lignocellulosic or non-lignocellulosic materials. Lignocellulosic materials refer to non-starch and fibrous part of the plants (cell wall) consisting of three major constituents (cellulose, hemicellulose, and lignin) which are strongly intermeshed and chemically bonded (Limayem & Ricke, 2012). On the other hand, non-lignocellulosic materials refer to non-cellulosic organic materials such as sugar (sucrose), starch, protein, and fat (oil) mainly used for nutritional purpose.

In order to achieve an efficient conversion of lignocellulosic biomass, it is necessary to have a better understanding on the cell wall structure and its compositions. The components which constitute the primarily part of a plant's cell wall are three major biopolymers consisting of cellulose, hemicellulose, and lignin as shown in Figure 2-2. Depending on the plant species, there is considerable variation in the relative amounts of each of these biopolymers within the cell walls. The composition, structure, and interactions of these biopolymers composing the lignocellulosic matrix serve many interrelated functions for the plant, including the primary function of providing structural features that create mechanical support, allowing for internal transport of water, nutrients, and photosynthetic products throughout the plant (Wyman, 2013). A

comparison on the amount of each of these polymeric constituents for some principal type of lignocellulosic materials is presented in Table 2-2. In contrast, biomass from animal wastes such as swine waste and solid cattle manure is rather poor in these polymeric constituents which make it a type of an inadequate material for torrefaction process. These polymeric constituents of biomass are further discussed in the subchapter 2.3.1-2.3.3.

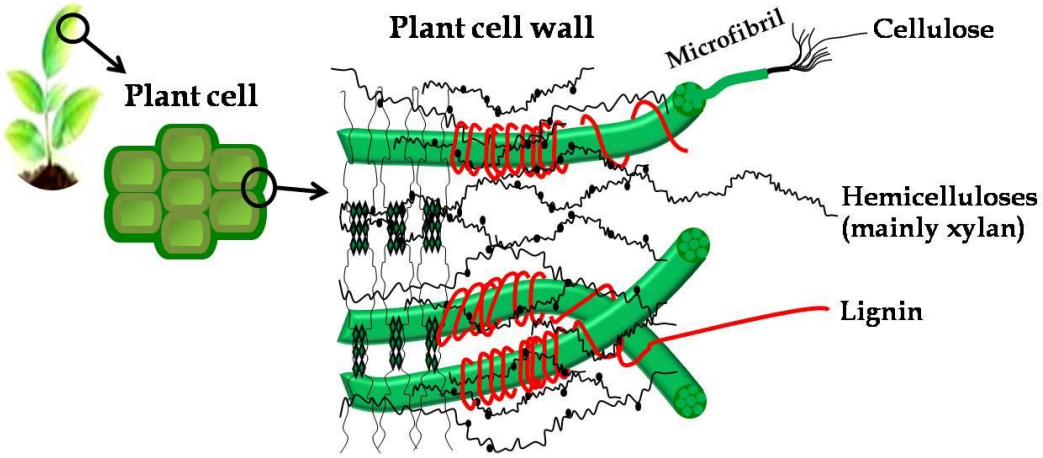


Figure 2-2: Lignocellulosic structure of plant biomass (Tomme *et al*., 1995)

Table 2-2: Polymeric constituents of various materials (Sun & Cheng, 2002)

Lignocellulosic materials	Cellullose (%)	Hemicellulose (%)	Lignin (%)
Hardwoods stems	40–55	24–40	18–25
Softwood stems	45–50	25–35	25–35
Nut shells	25–30	25–30	30–40
Corn cobs	45	35	15
Grasses	25–40	35–50	10–30
Paper	85–99	0	0–15
Wheat straw	30	50	15
Sorted refuse	60	20	20
Leaves	15–20	80–85	0
Cotton seed hairs	80–95	5–20	0
Newspaper	40–55	25–40	18–30
Waste papers from chemical pulps	60–70	10–20	5–10
Primary wastewater solids	8–15	NA	24–29
Swine waste	6.0	28	NA
Solid cattle manure	1.6–4.7	1.4–3.3	2.7–5.7
Coastal Bermuda grass	25	35.7	6.4
Switch grass	45	31.4	12.0

2.3.1 Cellulose

Cellulose is the main constituent of lignocellulosic biomass due to its large molecular weights of 500,000 units of monomers (Basu, 2010). It is a linear polysaccharide polymer consisting of a linear chain of D-glucose linked by β-(1,4)-glycosidic bonds to each other (Rowell, 2005). Cellulose chains are linked together by a number of intra- and inter-molecular hydrogen bonds as well as van der Waals forces, resulting in the form of microfibrils with high tensile strength (Ha *et al*., 1998). Figure 2-3 shows the chemical structure of cellulose with different hydroxyl groups in the chain. These hydroxyl groups increase the ability to form hydrogen bonds which enhance the hygroscopic property of lignocellulosic biomass. This hygroscopic (hydrophilic) nature increases the gap between cellulose chains and causes the lignocellulosic biomass to swell when immersed in water. For this reason, biomass may encounter shrinkage phenomena upon thermal treatment, causing dimensional variations and loss of moisture content (Nhuchhen *et al*., 2014).

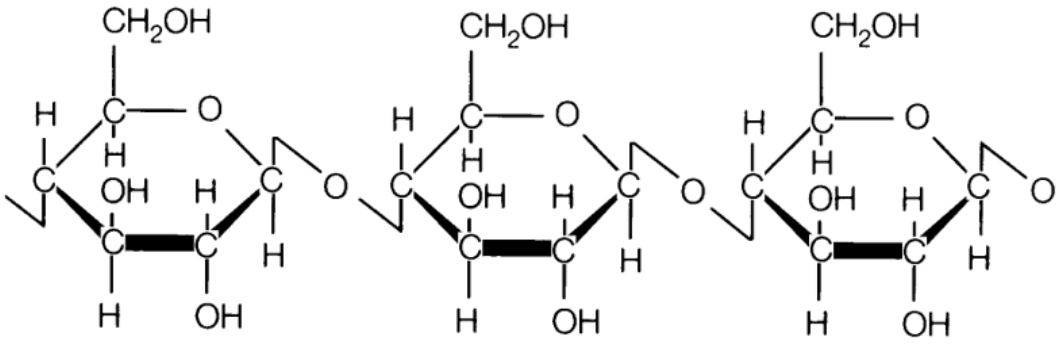
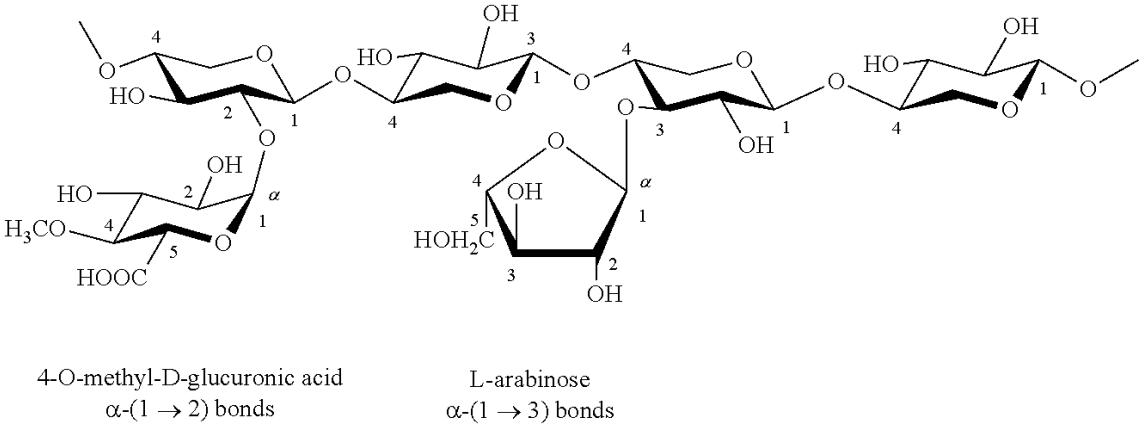


Figure 2-3: Chemical structure of cellulose (Nhuchhen *et al*., 2014)

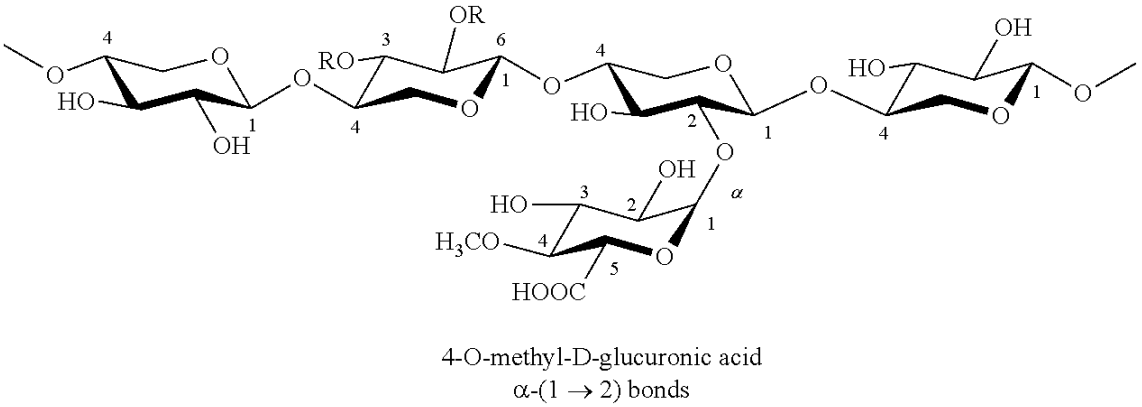
2.3.2 Hemicellulose

Hemicellulose is the second most abundant polymers in lignocellulosic biomass. In contrast to cellulose, hemicelluloses are more amorphous, random, and branched heterogenic polysaccharides consisting of various pentoses (xylose and arabinose), hexoses (glucose, galactose, mannose, and/or rhamnose), and acids (glucuronic acid, methyl glucuronic acid, and galacturonic acid) (Girio *et al*., 2010). Its random and amorphous structure makes it as the weakest constituent of biomass cells (Basu, 2010). Hemicellulose is composed predominantly of methyl- and acetyl- substituted groups which take part in releasing light volatiles gases such as CO and CO_2 upon low temperature thermal pretreatment (Rowell, 2005). Unlike cellulose, hemicellulose has a

lower degree of polymerization that results in substantial thermal degradation. Therefore, it contributes a significant effect on mass yield during torrefaction process. Figure 2-4 (a) and (b) show the hemicellulose structure for softwood and hardwood respectively. The softwood hemicellulose mainly consists of xylose, arabinose, mannose, galactose, and glucuronic acid while hardwood hemicellulose is mainly made up of xylose and glucuronic acid (Dhepe & Sahu, 2012).



(a)



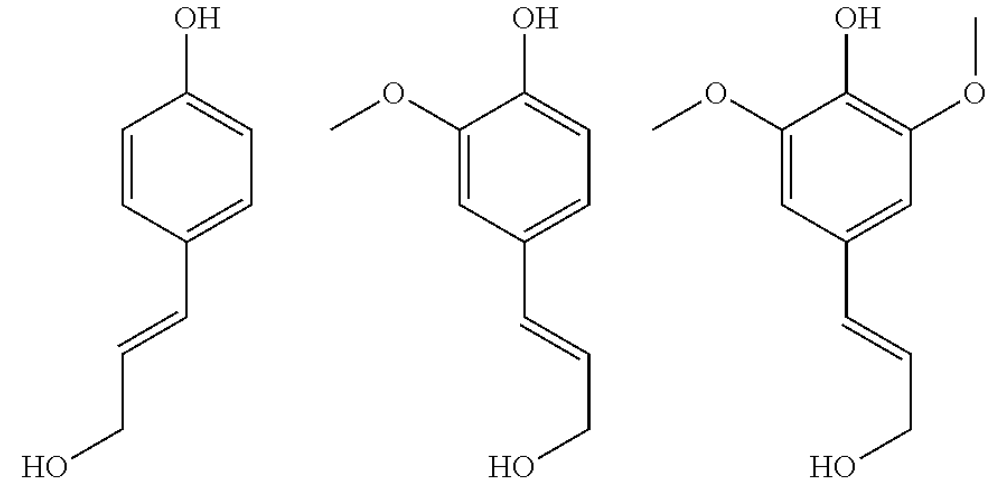
(b)

Figure 2-4: Chemical Structure of Hemicellulose: (a) Softwood; (b) Hardwood (Dhepe & Sahu, 2012)

2.3.3 Lignin

Lignin represents the third most abundant organic compound in nature after cellulose and hemicellulose. It is a complex network formed by polymerization of phenyl propane units and constitutes the most abundant non-polysaccharide fraction in lignocelluloses (Sanchez, 2009). Figure 2-5 shows three basic monomers in lignin (p-coumaryl alcohol,

coniferyl alcohol, and sinapyl alcohol) which are linked by alkyl–aryl, alkyl–alkyl and aryl–aryl ether bonds. Lignin acts as cement for the cross-linking between cellulose and hemicellulose to form a rigid three-dimensional structure of the cell wall (Palmqvist & Hahn-Hagerdal, 2000). It is also water insoluble and optically inert. These properties of lignin make it the most recalcitrant component of the plant cell wall in which the higher the lignin content, the greater the resistance of the biomass to chemical and biological degradation. It becomes a major barrier for utilization of lignocellulosic biomass in bioconversion processes. Furthermore, lignin is thermally stable over a wide temperature range of 100–900 °C depending on the precursors of the lignin (Yang *et al*., 2007). Thus, lignin remains the less modified component among other polymers and a biomass with higher lignin content is expected to yield more solid products.



p-coumaryl alcohol, coniferyl alcohol sinapyl alcohol

Figure 2-5: Three basic monomers of lignin (Albizati & Tracewell, 2012)

2.4 Palm oil and Oil Palm Biomass in Malaysia

Oil palm tree (*Elaeis guineensis*) originated from the tropical rainforests of West and Southwest Africa. It was first introduced to Malaysia in 1870 through the Singapore Botanic Gardens as an ornamental plant (Mohammed *et al*., 2011). Once its commercial value was recognized, the oil palm trees were grown in plantation on large scale. The tree bears fruit at the age of about two to three years. However, maximum yield can only be achieved in the age of about 12 to 14 years, which then continuously declines until the end of its economic life at 25 years old (Abdullah, 2003). It takes about five to six months to develop from pollination to maturity before it can be harvested. The fruits are developed in large condensed infructescence which is often called fresh fruit

bunches (FFB). The fruit which is rich in oil comprises a soft oily pulp (mesocarp) with a single seed (palm kernel) inside. The oil extracted from the pulp of the fruit is usually made into edible oil while the kernel is used mainly for soap manufacturing.

Palm oil is considered the world's largest source of oils and fats with 56.1 million tonnes (31.3%) of the world's total oils and fats output (Sime Darby, 2014). Consequently, oil palm is recognized as a major economic crop which has triggered the expansion of plantation area in Malaysia. Malaysia as a tropical region has also flavoured the development of oil palm cultivation. As the second largest oil palm-producing country that comes after Indonesia, Malaysia accounts for 39% of world's palm oil production and 44% of world's exports (MPOC, 2009). In 2012, Malaysia has produced 18.79 million ton of crude palm oil (CPO) as shown in Figure 2-6.

Each year, there is an increase in the amount of oil palm biomass wastes. In 2010, the oil palm biomass solid wastes accounted for 80 million tonnes of dry biomass and it is expected to rise to 100 million dry tonnes by the year 2020 (AIM, 2011). Oil palm biomass can be derived from different sources of production sites as shown in Figure 2-7. In term of land use, Malaysia had reached 5.08 million hectares of oil palm plantation in 2012, that increased by 11.8% in comparison with 2008 as shown in Figure 2-6. This large plantation area generated a vast amount of waste in the form of fronds and trunks. Most of these wastes are usually left to rot for soil regeneration or burnt on the plantation site. However, the Department of Environment has discouraged burning of these materials due to pollution and possible forest burning problems (Sopian *et al*., 2000). This large volume and type of oil palm residues are also expected to rapidly increase and will become a serious problem in the future. Hence, the best solution is to minimize and recycle the waste, and recover the energy as much as possible for further utilizations such as combustion, gasification and co-firing.

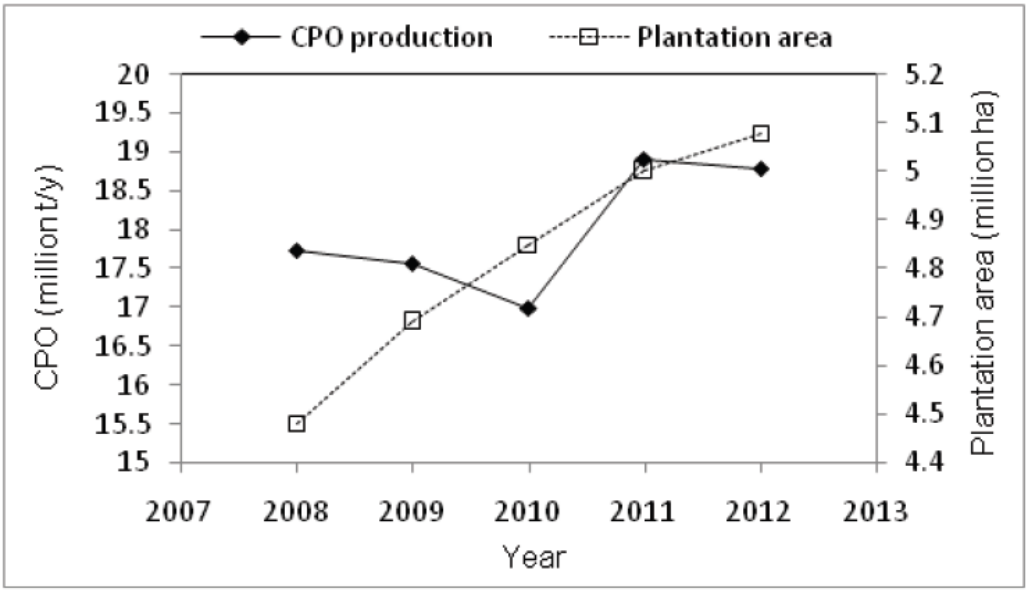


Figure 2-6: Crude palm oil (CPO) production and plantation area in Malaysia (Aljuboori, n.d.)

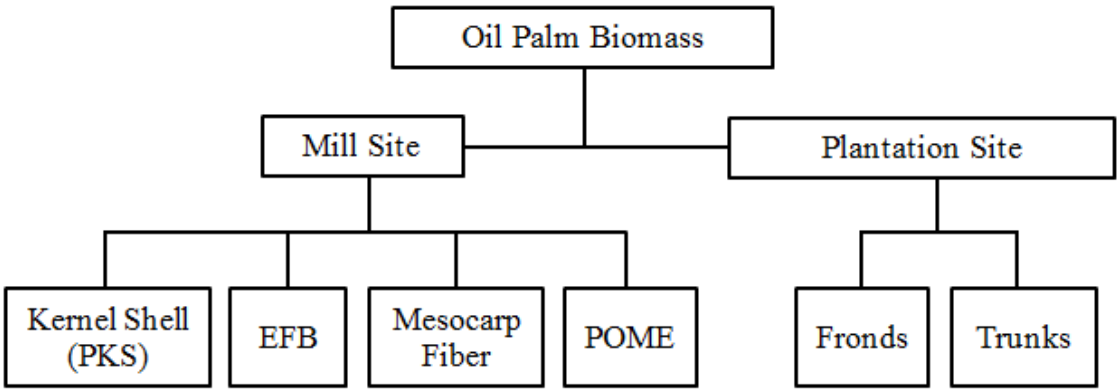


Figure 2-7: Oil palm biomass residue and source of generation

2.4.1 Oil Palm Fronds (OPF)

Oil palm frond (OPF) is the most abundant type of oil palm waste. They are largely available during felling operations and pruning during fruit harvesting. However, at present OPF is not given much attention unlike the other types of biomass produced by oil palm tree. Other than being utilized as ruminant feedstock, they are often dumped at the plantation site for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling (Zahari *et al*., 2003). Efforts in studying oil palm frond gasification based on experiment approach was reported by Atnaw *et al*. (2011), bearing a potential result where OPF might be a prospective biomass fuel for heat and energy generation. Hence, there is an opportunity to utilize OPF for biomass energy generation

due to its abundant supply and considerable energy content. Furthermore, OPF is a lignocellulosic material available at a very low cost which would represent a valuable renewable source of various products and chemicals (Goh *et al*., 2010a). Table 2-3 shows some chemical contents of lignocellulosic OPF.

Table 2-3: Chemical compositions of OPF

Components	Abnisa *et al*. (2013)	Wanrosli *et al*. (2007)
Cellulose (%)	50.33	47.60
Hemicellulose (%)	23.18	34.60
Lignin (%)	21.70	15.20
Ash (%)	0.24	0.70

2.4.2 Oil Palm Trunks (OPT)

The average economic life-span of oil palm trees is usually about 25 years due to decreasing yield or increasing height which causes harvesting difficulty. There is a large quantity of cellulosic raw material generated in the form of felled trunks during replanting activities and it contributes a large amount of agricultural waste in Malaysia. Oil palm tree is around 7-13 m in height and 45-65 cm in diameter, measuring 1.5 m above the ground level (Khalil *et al*., 2010). The OPT has a number of potential uses such as lumber, pulp and paper, reconstituted boards, bio-composites, animal feed, and fuel (Mokhtar *et al*., 2008).

However, in most of the practices, oil palm trunks are shredded after felled, and are disposed by burning or leaving them on the ground to rot. Both processes have disadvantages in term of environmental sustainability. Burning leads to air pollution and it takes more than 1 year for them to completely decompose, which can hinder the replanting process (H'ng *et al*., 2011). To overcome this problem meanwhile applying zero waste management solution, utilization of OPT as biomass feedstock will be a solution approach for making use of these abundant waste. Like other wood-based biomass materials, OPT is also rich in its lignocellulosic content as shown in in Table 2-4.